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Putting domestic gardens on the agenda using empirical spatial data: The case of Flanders

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A B S T R A C T

Spatial data are considered to be an essential entry point to get domestic gardens on the agendas of land use monitoring, spatial planning and environmental policies. As a green facet of urbanization, gardens cover a substantial part of land all over the world. Moreover, domestic gardens deliver several ecosystem services. The sustainability turn in planning however focuses on densification. In densification scenarios, planners could consider domestic garden area as a land reserve. Yet, due to a lack of data they would be ill-informed on the domestic garden services and potentials and not be able to make well-founded choices. So, the strategic value of domestic gardens remains largely unquestioned. By developing and applying a mixed methodology that combines an existing land use map with empirical data, this study provides data and insights on the spatial coverage, distribution and growth of domestic garden area in Flanders (the northern region of Belgium). The results show that 8% of the Flemish area is covered by domestic gardens, as well as 21% of the total area of Flemish residential cores. The highest concentrations are found in peri-urban areas and around ribbon developments. About 8% of the garden area that existed in the period 2002–2005 was new compared to the period 1988–1990 and occupied mainly former agricultural land (90%). The results clarify the regional significance of domestic gardens in terms of spatial coverage. The developed mixed methodology made the domestic garden theme analysable. The insights offer an entry point for a debate on the strategic value of domestic gardens.

Introduction

Urban and residential fabric is usually perceived as a mosaic of buildings, roads and artificially covered areas (Gill et al., 2008). Yet a closer look behind this urban façade confirms the existence of thousands of domestic gardens (Gaston, Smith, Thompson, & Warren, 2005; Gaston, Warren, Thompson, & Smith, 2005; Loram, Tratalos, Warren, & Gaston, 2007; Smith, Gaston, Warren, & Thompson, 2005) differing in size, composition, use and management. Domestic gardens are beyond the scope of land use statistics, spatial and green structure planning and environmental policies (Perry & Nawaz, 2008; Thompson et al., 2003). Main reasons are their private and small scaled character (Phillips, Page, Saratsi, Tansey, & Moore, 2008; Van Delm & Gulinck, 2011) and the lack of data. As a consequence, the value of domestic gardens as a strategic land use remains largely unquestioned.

Detailed information on the stock of domestic gardens is needed to develop all-inclusive policies that include domestic gardens. We consider spatial data as an entry point for the theme of domestic gardens on the agendas of research and policy. Such data will allow to demonstrate the spatial and strategic significance of domestic gardens in relation to more traditional and better acknowledged land use categories. It will also allow to better assess the impacts and the ecosystem services of domestic gardens at a regional scale.

Since regional spatial data on domestic gardens is only limited available, a mixed methodology was developed. This research aims to collect data on the available stock of garden area and its spatial characteristics for Flanders, the northern region of Belgium. By placing our results in the broader context of densification, we want to start a debate on the strategic significance of domestic gardens.

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In need for new perspectives on domestic gardens?

The unsealed and green characteristics of domestic gardens invite to consider them as strategic land use units. Although scientific literature on gardens is scarce in comparison to literature on forests, nature conservation areas and public parks, it provides substantial information on the ecological, social and economic characteristics, functions and services of domestic gardens.

Positive effects of gardens on well-being and physical health are described (Clayton, 2007; Dunnett & Qasim, 2000; Gross & Lane, 2007; Milligan, Gatrell, & Bingley, 2004) as well as their role for biodiversity (Daniels & Kirkpatrick, 2006; Goddard, Dougill, & Benton, 2010; Tratalos, Fuller, Warren, Davies, & Gaston, 2007). Also economic relevance (Dunnett & Qasim, 2000), organic waste processing (Barr et al., 2013; Dewaelheyns, Elsen, Vandendriessche, & Gulinck, 2013) and home food production (Alayon-Gamboa & Gurri-Garcia, 2008; Calvet-Mir, Gómez-Baggethun, & Reyes-García, 2012; Niñez, 1987; Pandey, Rai, Singh, & Singh, 2007; Reyes-García et al., 2012; Siviero, Delunardo, Haverroth, de Oliveira, & Mendonca, 2011; Taylor & Lovell, 2012) are of general interest. Gardens also have a role in global challenges like climate change. The use of water (Aitken, Chapman, & McClure, 2011; Breyer, Chang, & Parandvash, 2012; Syme, Shao, Po, & Campbell, 2004), greenhouse gas emissions from lawn fertilizer usage (Bijoor, Czimczik, Pataki, & Billings, 2008; Howarth, Boyer, Pabich, & Galloway, 2002; Kaye, Groffman, Grimm, Baker, & Pouyat, 2006; Livesley et al., 2010; Lorenz & Lal, 2009; Trudgill, Jeffery, & Parker, 2010), and the storage of carbon by garden soils (Groffman, Law, Belt, Band, & Fisher, 2004) are a few climate related aspects. For a review on the contribution of the domestic garden to urban green infrastructure, we refer to Cameron et al. (2012).

Domestic gardens in urban development and spatial planning

The origin of domestic gardens relates strongly to the history of urbanization. In many languages the words for 'garden' refer to the act of enclosing outdoor space (Turner, 2005). The first gardens appeared when early settlements and cities started to develop (Niñez, 1987; Pregill & Volkman, 1999; Turner, 2005) and gardens and urbanization evolved in relation to each other. In fact, many of the world's best-designed cities have been inspired by garden concepts (Turner, 2005).

In the nineteenth and early twentieth century, several housing and city models were developed based on the social and ecological benefits of both public and private green, for example the 'Garden City' of Ebenezer Howard (1970) and the 'Lobe City' model of Tjallingii (1995). Improving the urban living quality was thereby a main argument. The promotion of domestic gardens has even been explicit in the development of the garden cities Letchworth and Welwyn in Britain (Pregill & Volkman, 1999) and by the promotion of the housing model of a single-family house with a garden in Belgium (De Decker, 2011; Van Herck & Van Avermaete, 2006).

The total area of domestic garden is increased by both planned and unplanned urbanization processes. Residential development is often accompanied with garden area (private or collective). Also unplanned and small scaled non-agricultural processes lead to an increase of garden area in peri-urban and rural areas. For example the re-use of former agricultural buildings as bed & breakfast or wellness centre (Verhoeve, De Roo, & Rogge, 2012) is often accompanied with an increase of garden area. But the increase of garden area is not only a consequence of housing. Gardens themselves may be an object of investment and restructuring (Paquette & Domon, 2003; Phillips et al., 2008). For example, gardens in the countryside or peri-urban areas are expanded by annexing (a part of) an adjacent agricultural parcel to the garden. Such autonomous processes (Antrop, 1998) are often deviant from land use policies and hard to grasp without empirical data.

In reaction to some undesirable effects of continuing urbanization of open space, like increased fragmentation and high mobility costs, a 'sustainability-turn' appears in planning theory (Atkinson-Palombo, 2010; Berke, 2002). Concepts like 'smart growth' and 'new suburbanism' proclaim the raising of residential densities in both new-growth areas and existing neighbourhoods as a solution for the space consuming effects of sprawl (Atkinson-Palombo, 2010; Downs, 2005; Filion, 2003). In horizontal densification models – essentially by infill of remaining open space in between housing – the domestic garden area can be considered as land stock for housing development.

The long-term effects of densification initiatives are not known yet (Preuss & Vemuri, 2004), neither are the full range of related aspects. For example from the perspective of biodiversity, Olive and Minichiello (2013) state that smart growth programmes have not yet taken seriously into account the recovery of endangered species. As densification programmes are likely to be realized at the expense of the domestic garden area and their associated value (for example for biodiversity, food production and climate adaptation and mitigation), it should be clear what the effects of densification on these functions could be.

Spatial data on domestic gardens

There is only a handful of studies that focus on the spatial footprint of domestic gardens, since they are often not represented by traditional mapping approaches (Gill et al., 2008). Perry and Nawaz (2008) and Mathieu, Freeman, and Aryal (2007) point out that little information is available about the extent of individual gardens. Nevertheless, several studies confirm the spatial importance of gardens. For example, in Edinburgh, Belfast, Leicester, Oxford and Cardiff (U.K.), domestic gardens take up between 22 and 27% of the total area within the administrative city boundaries (Gaston, Warren, et al., 2005; Loram et al., 2007; Tratalos et al., 2007).

Domestic gardens also represent an important share of urban green space. They take up 35–47% of urban green in the United Kingdom (Loram et al., 2007) and 42% of the urban green in the Brussels Capital Region (Belgium) (Van de Voorde, Vlaeminck, & Canters, 2008). In New Zealand, the vegetated garden area occupies 46% of the residential area, and 36% of the total urban area (Mathieu et al., 2007).

These studies essentially deal with urban domestic gardens, although gardens are also an important land use component in peri-urban and rural areas (Marco et al., 2008). Because of their focus on urban areas, none of the above studies sufficiently informs about regional spatial coverage and distributions of gardens. This limits a full appreciation of strategic values of the total garden area at regional or national level.

Research objectives

From a spatial perspective, domestic gardens can be considered both as consumers of open space and as land stocks for housing development. Surprisingly little information is available on the spatial footprint and characteristics of domestic gardens. The overall goal of this research is to make the domestic garden theme analysable by collecting data on the available stock of garden area and its spatial characteristics.

We developed a mixed methodology to measure the spatial footprint of domestic gardens. This methodology involves the improvement and update of an existing land use map by using empirical data. The empirical data is collected by digitizing

domestic gardens and houses from orthophotographs. The case area is Flanders, the northern region of Belgium. The analysis of the obtained spatial data focuses on three aspects: coverage, distribution and growth of domestic garden area. Coverage includes both the size of individual gardens and associations with building types as well as the total garden area in Flanders. Distribution gives a more detailed image of different concentration areas of gardens in Flanders, while growth focuses on the evolution of garden area over a period of 15 years.

Case study Flanders

Flanders, the northern region of the federal state of Belgium, is strongly urbanized and characterized by urban sprawl and fragmentation (Antrop, 2004; European Environmental Agency (EEA), 2006; Kasanko et al., 2006). Flanders can be seen as a case study that is inspiring for other regions. It is considered a key-example of a small-scaled and multifunctional area, which makes it an interesting laboratory for research on peri-urban and ordinary landscapes. Especially such peri-urban and urban-rural fringe landscapes are increasingly becoming important (Matthews & Selman, 2006; A. Scott, 2011; Scott et al., 2013; Vouligny, Domon, & Ruiz, 2009), both due to acknowledgement from policy (e.g. Landscape convention (Council of Europe, 2000)) and increasing urbanization worldwide. Yet, they hardly receive attention in spatial policies and sustainable management (Scott et al., 2013).

According to national statistics, 25% of the territory is categorised as 'built-up parcel' (NIS, 2011). Moreover, the area of sealed surfaces in Flanders of 12,9% is far above the European average of 1.8% (Overloop et al., 2011). But Flanders is also rich in domestic green. According to the topographic land use map from the National Geographical Institute in Belgium (NGI, 2004) 1,726 km^2 or 13.4% of the Flemish area is covered by a land use category 'Garden'. About 82% of Flemish households live in a house with a garden or terrace (Bomans, Dewaelheyns, & Gulinck, 2011b). In the nineteenth and early twentieth century the Belgian Government strongly promoted and subsidised home ownership of a 'single family dwelling with garden' amongst the working and lower-middle classes. This housing model was seen as an important safety net to counteract periods of industrial unemployment and secure social peace (De Decker, 2011; Meert, 2000).

After the Second World War, the housing ideal of a home-with-a-garden became reality for the majority of the people due to an increase in prosperity, improved social security and government subsidies for private housing construction (De Decker, 2011; Van Herck & Van Avermaete, 2006). In the second half of the twentieth century residential development continued as urban sprawl, more linked to increased affordability and mobility than in the previous period (De Decker, 2011). Currently, the phenomenon of garden expansion is observed in the rural part of Flanders (Bomans, Steenberghen, Dewaelheyns, Leinfelder, & Gulinck, 2010), facilitated by the Agricultural Holdings Act. This law states that land owners are able to revoke up to 0.2 ha of the leased land to be used for family goals like a garden or playground, if this land is connected to his or her dwelling (Belgisch Burgerlijk Wetboek (Belgian Civil Law), 1969, update until 06–07–2009).

Whilst Belgium and its regions may be rather unique because of (i) political choices in the past in favour of a single family dwelling with garden and (ii) a housing policy with liberal rights of ownership, the model of a house with garden is also present in other countries. For example, several studies on food production in home gardens focus both on developing countries (e.g. Alayon-Gamboa & Gurri-Garcia, 2008; Pandey et al., 2007; Siviero et al., 2011; Trinh et al., 2003) as well as developed countries (e.g. Reyes-García et al., 2012; Taylor & Lovell, 2012). So, domestic gardens exist all over the globe, in all continents and several cultural contexts. This makes domestic gardens a global theme that exceeds the borders of the Flemish case studied in this paper.

Data and methodology

The topographic land use map, published in 2004 by the National Geographical Institute in Belgium (NGI, 2004), is the base for this research. This land use map was produced by an on-field interpretation and completion of black and white aerial photographs (scale 1:50.000, production dates ranging between 1995 and 2003) using a field protocol from 1991. The NGI land use category 'Garden' includes not only domestic gardens, but also parts of public green areas. Also, the map can be considered as outdated.

Therefore we want to determine and update the fraction of domestic gardens within the general NGI land use category 'garden'. In addition, we want to collect currently unavailable data on individual garden sizes and related building types. The improvement and update of the topographic land use map from the National Geographical Institute (NGI, 2004) was done by means of linear regression. This regression was based on empirical spatial data of individual gardens that were collected by an orthophotograph analysis of 60 25 ha square segments.

Definition of domestic garden

A domestic garden is defined in this study as the residential parcel without the associated house. The parcel can be privately owned or rented. Hobby farming (either as extension of the garden, or as separate units) as well as storage space for building materials or refuse are excluded from the domestic garden category. Also wood lots on the garden parcels are not categorized as garden. This matches the garden criteria of the NGI field protocol, according to which parts of garden parcels where the crowns of groups of trees touch each other were categorized as forested.

Also domestic gardens associated with the dwellings of farmers are included, but the area used by the farmer for professional agriculture (professional greenhouses, horticulture) is not. Private greenhouses used for gardening are included. Gardens that are spatially not associated with housing, like dispersed single-plot gardens in agricultural land and allotment gardens, are not considered as domestic gardens. Allotment gardens altogether cover less than 200 ha of Flemish area (Allaert, Leinfelder, & Verhoestrate, 2007). Green roofs and apartment terraces are also excluded, since it is too difficult to identify these features on orthophotographs.

Sampling design and digitization

Detailed spatial data on individual gardens was collected by an orthophotograph analysis in a GIS-environment. The orthophotographs were sampled using the Area Frame Sampling technique (AFS). AFS is a statistical sampling technique that is widely used (Bettio, Decliné, Buryas, Croi, & Eiden, 2002; FAO, 1995; Gallego, 1999) to make spatial estimations about a material or object of interest within an 'area frame' or study area, being Flanders within this research. The area frame is divided into Primary Sampling Units (PSU), out of which a random selection is made (Cotter & Nealon, 1987). Within the selected PSU's, spatial data on the object of interest is collected, in this case the land use 'domestic garden'.

To ensure accurate estimations within the sample, the area frame was divided into four homogeneous strata or groups (Mandana, 2002) by a *K*-means clustering of all 308 Flemish municipalities. Doing so, variation is reduced within the strata, while the variation between the strata is increased (EPA, 2002; Lauridsen,

2004). The clustering was based on the area-percentages of the following land use categories, calculated from the existing topographical land use map (NGI, 2004): (i) garden, (ii) agriculture, (iii) impervious area and (iv) the ratio of garden area over impervious area. Agriculture and impervious surfaces are aggregates of several distinct land use classes. Agriculture encompasses arable land, pasture and meadowland, orchard and tree nursery, while impervious areas include buildings, industrial areas, roads and the railway network. The *K*-means clustering resulted in four municipality clusters (Table 1). The balanced cluster has a proportion of the three land use classes equivalent to the land use proportion in the overall topographical map (NGI, 2004). The other three clusters are each dominated by dominant specific land use category.

Next, the PSU's were defined as segment samples for reasons of higher accuracy compared to point samples (Gallego, 1999). The segments were defined by a raster built up out of 25 ha squares. For complex and diverse landscapes, 25 ha is a commonly used study unit (Bunce et al., 2008; Cooper & McCann, 2002). According to Bettio et al. (2002), the optimal number of segments ensures a representative sampling without being inefficient due to a too large number of segments. Based on a One-Way ANOVA statistical test, a total of 60 segments was considered sufficient to be representative for Flanders (p-value = 0.878, $\alpha = 0.05$). The null-hypothesis stated that there are no significant differences between the mean area of gardens (calculated from the NGI land use map) in sampling sets with different sample sizes (60, 80, 100 and 140 segments). The random selection of the segments was conducted proportionally, taken into account the total area of the stratum: bigger strata are assigned more segments.

Within each segment, individual garden areas and their related houses were identified on digital orthophotographs taken in the period 2002–2005 (orthophotographs, mid-scale 1/12.000, colour, 2002 provinces Flemish-Brabant and East-Flanders, 2003 provinces Limburg and Antwerp and 2005 province West-Flanders, AGIV) and digitized in a GIS-environment. These orthophotographs were in general more recent than those used by NGI to support the production of the topographic land use map (production dates of the orthophotograps: between 1995 and 2003). The garden parcel was demarcated as the parcel on which a house is located. The house itself was not included in the garden area and was digitized as a separate polygon, including an attribute on building type (terraced, semi-detached or detached). The final dataset for each parcel included the house area, the garden area and the building type. Fig. 1 illustrates the digitalization result within one segment and the differences with the topographical land use map (NGI, 2004).

Garden size and relationship with building types

Since so far spatial data on domestic gardens were lacking, we looked for possible indicators for garden size. The results of the orthophotograph interpretation were used to determine area statistics of individual gardens. Only gardens that fell completely within the segments were retained for further analysis.

Domestic gardens are per definition associated with houses. Houses are physical and functional units that are much better inventoried through enquiries, systematic censuses, aerial photographs, etc. So, it is interesting to deduce accessible house-bound indicators of garden characteristics. More particularly, we analysed correlations between garden area on the one hand and building type and house area on the other hand using two hypotheses.

The first hypothesis is that smaller gardens are mainly associated with terraced buildings, while larger gardens will be more likely to occur in relation to detached houses. The median garden area was compared between the three building types. The non-parametric Kruskal–Wallis One-way Analysis of Variance was used since the variable garden size was not normally distributed (Table 2).

The second hypothesis states that smaller houses are associated with smaller gardens, while larger houses will be related to larger gardens. At first sight this is obvious, but evolutions in housing size in Flanders indicate a strong growth of the number of smaller houses, apparently without a comparable decrease in parcel size (Vanneste, Thomas, & Goossens, 2007). Since both variables (garden area and house area) were not normally distributed (Table 2), the correlation was tested by means of the non-parametric Spearman's Rho correlation coefficient. The significance was tested by means of a t-test. All statistical tests were conducted in SPSS 15.00 and 20.00.

Coverage percentage and regional distribution

The coverage percentage of Flanders by domestic gardens was extrapolated from the digitized individual garden areas using a linear regression formula. For all 60 segments, data from the orthophotograph analysis were compared to the topographic land use map and differences in garden area percentages were calculated. Segments with a difference in garden area of more than 5% were visually analysed to identify the differences.

Next, a linear regression was used to systematically compare the garden area percentages according to the topographic map (the independent variable) with the garden area percentages according to the orthophotograph analysis (the dependent variable). Both variables were log-normalized (Table 2). With the regression model, the total area of the Flemish garden complex was estimated for different spatial units, leading to a more accurate baseline map and an improved image of the total domestic garden area in Flanders.

To clarify the spatial distribution of the garden area, the garden area percentage was calculated for the two spatial units 'statistical sectors' and 'residential cores'. A statistical sector (NIS, 2005) is a small administrative subunit of a municipality for which the Directorate-General Statistics Belgium (ADSEI) collects different types of statistical data. They are characterized by social, economic, urban and morphological criteria. The unit of a statistical sector gives better insight into (i) the distribution of garden area in the urban–rural gradient because of its fine scaled character and (ii) linkages

Table 1
Four clusters of Flemish municipalities. In bold are the percentages that define the cluster character.

Clustername	Area percentage gardens [%]	Area percentage agricultural land use [%]	Area percentage impervious area [%]	Garden area/impervious area	Area [km^2]	Number of segments
Flanders	13.4%	56.45%	13%[a]	1.03	13,599	60
Balanced cluster	**15 %**	**55%**	**11%**	1.30	3837	20
Agricultural cluster	9%	**73%**	10%	0.94	4751	25
Garden cluster	**24 %**	38%	13%	1.89	766	5
Impervious cluster	17%	38%	**27 %**	0.69	2130	10

[a] Gulinck et al. (2007).
Data source: Topographical land-use map (Nationaal Geografisch Instituut (NGI), 2004)

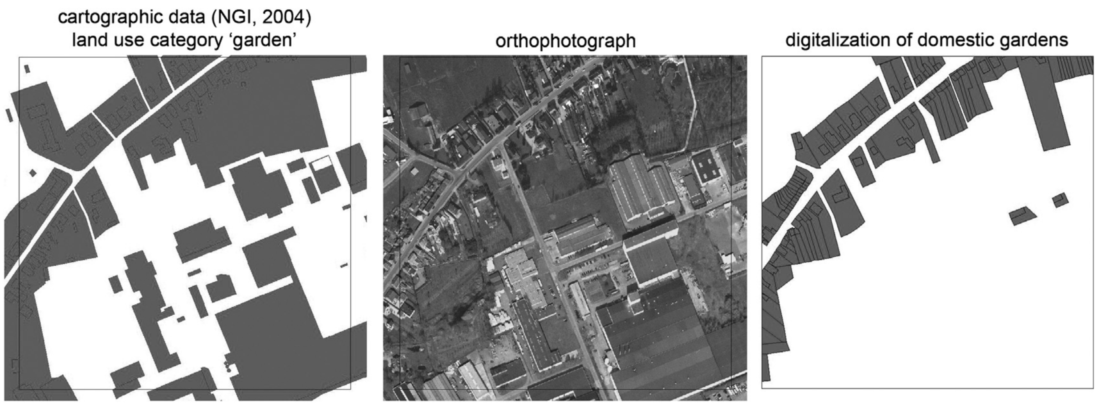

Fig. 1. Illustration of the orthophotograph analysis for segment 21: comparison between the topographical land use map, orthopotograph and digitized gardens and houses. Gardens are black, buildings are grey.

with building patterns. The residential cores are a subset of the statistical sectors, only including cities, village centres and hamlets.

For the whole of Flanders, the initial garden area was calculated per statistical sector by means of zonal statistics (statistics type 'sum'), based on the initial topographical land use map (resampled to a cell size of 100 m^2), and converted into garden area percentage. Next, the linear regression formula defined in paragraph 2.2 was applied on this initial garden area percentage per statistical sector. This leads to an improved garden area percentage per statistical sector. The same procedure was repeated to calculate the garden area percentage of the residential cores.

Measuring growth of the garden area

We introduce two types of garden growth: passive and active. Passive growth is a consequence of new housing development. In this perspective, the garden is the residual part of the developed parcel. Active growth is the result of an active search for land, specifically for its intended use as garden. The garden itself is an object of investment by the expansion of existing domestic gardens.

In order to collect data on the growth of garden area, a temporal analysis was conducted starting from the same sample of segments. Orthophotographs from the period 1988–1990 (digital orthophotographs, colour, Eurosense, 1/10.000, 1988–1990, date of publishing 1990, OC-GIS Flanders) were compared with the digitized garden polygons based on the orthophotographs from the period 2002–2005. Since such orthophotographs were not available for the period 1988–1990 for 16 of the 60 segments, the temporal analysis was limited to 44 of the 60 segments. The digitized garden polygons were assigned two extra attributes: 'completely or partially new' and 'located in agricultural land'. The first one helped to detect a difference between active and passive growth. The latter allowed to estimate the share of agricultural land converted to domestic garden.

Results & discussion

Garden size and relationship with building types

The average area of an individual private garden in Flanders is 571 m^2. About 30% of the identified gardens has an area between 250 and 500 m^2 (Fig. 2). Most of the gardens related to terraced houses are smaller than 100 m^2. Gardens between 100 and 250 m^2 are almost equally distributed amongst the terraced and semi-detached building types. Larger gardens, between 500 and 750 m^2, are typically associated with detached houses. The semi-detached houses fall in between the two other groups, with most of the gardens having an area between 250 and 500 m^2. The median areas of the gardens with detached, semi-detached and terrace houses are respectively 703 m^2, 324 m^2 and 141 m^2.

Our results coincide with the study of Loram et al. (2007) in the United Kingdom, who found that the median garden area of detached houses was twice the median of the garden area of semi-detached houses, which in turn was also twice the median of the garden area of terraced housing. In our sample, detached houses constitute the largest share with 47%, while semi-detached houses account for 34% of the sample and terraced houses for 19%. These observations on building type occurrence are somewhat opposite to Loram et al. (2007), who found mainly terraced houses in their sample and detached housing making up the smallest portion of the sample. This may be due to a difference in the demarcation of the municipal boundaries or in the sampling methodology, as their sample was being set up as a point sample selecting randomly 1000 building polygons and associated gardens within the city boundary. Also differences in building morphology between the United Kingdom and Belgium should be taken into consideration. Flanders, with its typical ribbon development (Antrop, 2000; Verbeek, Pisman, Leinfelder, & Allaert, 2011), is characterized by more semi-detached and detached housing.

The histogram in Fig. 3 confirms the hypothesis that smaller gardens are mainly associated with terraced houses, while larger gardens rather occur with detached houses. The Kruskall–Wallis

Table 2
P-values for the Kolmogorov–Smirnov tests for the variables and their transformations. Italics refer to the transformed variables.

Variable	*P*-value Kolmogorov–Smirnov[a]
Garden area	0.000
LN (garden area)	*0.000*
Log (garden area)	*0.000*
SQRT (garden area)	*0.000*
House area	0.000
LN (house area)	*0.037*
Log (house area)	*0.037*
SQRT (house area)	*0.000*
Garden area percentage topographical map	0.032
LN (Garden area percentage based on topographical map)	*0.261*
Garden area percentage based on digitalization	0.008
LN (Garden area percentage based on digitalization)	*0.306*

[a] $\alpha = 0.05$.

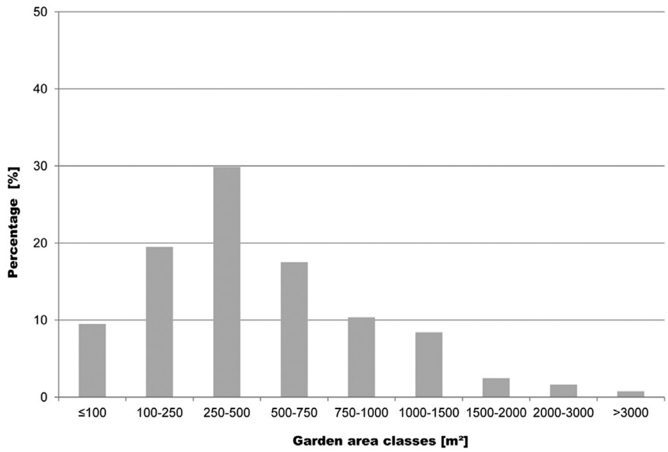

Fig. 2. Distribution of the digitized gardens over garden area classes: percentage of gardens per area class.

One-way Analysis of Variance rejects the null hypothesis that each building type has the same distribution of garden sizes (p-value of 0.000, $\alpha = 0.05$). The mean ranked garden area differs significantly between the three building types. So the housing type is a useful indicator for estimating associated garden areas. This corresponds to the findings for the U.K. Loram et al. (2007) found that the individual garden area is closely associated with housing type: semi-detached houses have larger gardens than terraced houses and smaller gardens than detached houses. Smith et al. (2005) found similar results for back gardens. Also the second hypothesis, that smaller houses are associated with smaller gardens and larger houses with larger gardens, is confirmed by the high Spearman Rho correlation coefficient of 0.672 (p-value of 0.00, $\alpha = 0.05$ and $\alpha = 0.01$). So also the housing area is an indicator for the associated garden size.

Housing type and housing area are potential indicators for garden size. This puts forward the possibility of using existing census data on housing characteristics to obtain more detailed insights. For now, the regional dispersal is only incorporated in the area percentage of domestic gardens per spatial unit (the statistical sector). Based on housing characteristics, future research can better evaluate the regional distribution of garden sizes.

As scenarios and land use models indicate an increase in the number of houses, it is interesting to grasp whether the relation between house and garden stays stable or evolves, in space (distribution) and time. Future research on the relation between house characteristics and garden size could for example take into account the date of construction of the houses to grasp the evolution of garden sizes. It is possible that the correlations between garden and housing area may evolve or even become less clear due to changes in policies or market prices. The ratio of garden over house size may become smaller, or there may be a trend towards more public or collective gardens instead of private gardens. The results presented here can be considered a zero- reference for future research on the garden-house relationships in Flanders.

Regional coverage by domestic gardens

Our orthophotograph analysis shows a smaller overall size of the area occupied by gardens in comparison to the reference cartographic data (Fig. 4). In 19 of the 60 segments, the difference in garden area between the land use map and the orthophotograph analysis was more than 5%. Several categories of land use, such as sand or clay-pits, farms and agricultural land, forest and forested parts of parcels, fallow (parts of) parcels and parcels for recreational farming, were classified as 'garden' by the NGI cartographers. The core of the scatter plot suggests a linear correlation between the garden area percentages according to the topographic map and our orthophotograph analysis. The bivariate Pearson correlation coefficient (0.866) and the determination coefficient R^2 (0.745) indicates that 75% of the variance of the digitized garden area percentage is explained by the garden area percentage according to the topographical land use map (NGI, 2004). The null hypothesis of the variance analysis, stating that the regression coefficient equals zero, is rejected ($p = 0.000$).

With the linear regression formula

$$V = -0.472 + 1.002\ U$$

in which $U = \ln$ (cartographic garden area percentage) and $V = \ln$ (digitized garden area percentage), the total area of domestic gardens in Flanders is calculated to be 8.2% (or 1,100 km^2) of the Flemish territory. This is less than the 13.4% (or 1,726 km^2) according to the reference topographical map (NGI, 2004). In comparison with other land uses the Flemish garden complex still takes up an important green area (Table 3). In comparison: forest area and nature conservation areas cover respectively 10% and 2.5% of the Flemish area. For these land uses, a wide range of

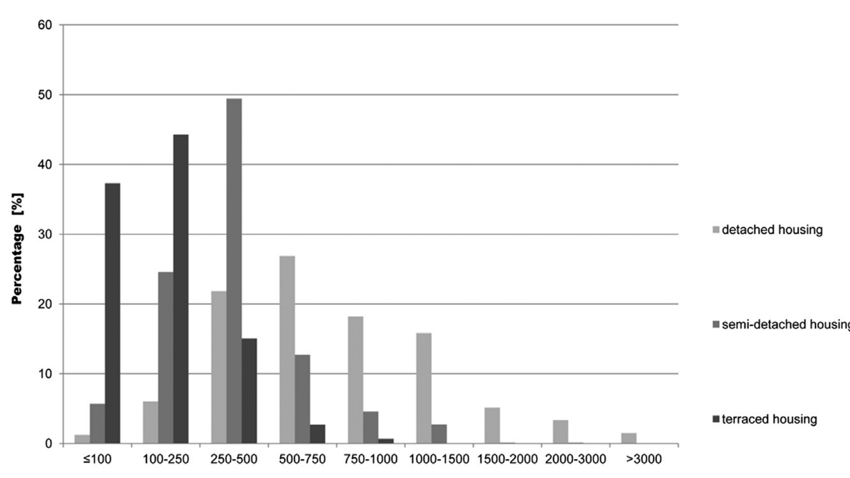

Fig. 3. Histogram of garden area per building type: percentage of gardens per area class according to building type.

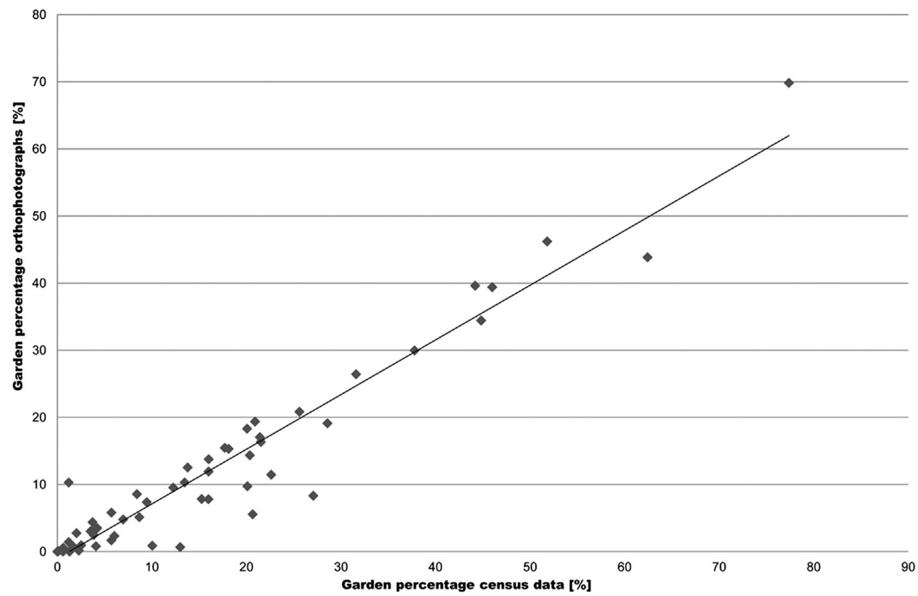

Fig. 4. Linear correlation between the garden percentages by the cartographic data and by the digitized data based on orthophotographs.

policy goals exists as well as specific research institutions and policy domains. Although they cover a comparable or even larger area, domestic gardens are not part of any policy domain or goals in Flanders.

The regional distribution of garden area

The garden area percentage per statistical sector is shown in Fig. 5. The average garden area percentage is 16.4%, and the maximum garden share is 63%. In the Brussels Capital Region, green areas are unequally distributed according to Van de Voorde et al. (2008). They encountered the highest proportion of green areas in the neighbourhoods near the capital. In the 19th and 20th century belts domestic garden cover up to 70% of the green area. Our garden distribution map shows similar patterns for Flanders, with a concentration of gardens especially around city and town centres.

In Fig. 6 a lower concentration of gardens is visible inside the city centre as compared to a higher concentration of gardens in the areas surrounding the centre and in semi-urban areas (e.g. Ghent, Bruges, Antwerp and Leuven). Only the agricultural areas in the west and southeast and the larger forest areas in the east of the region have a smaller fraction of gardens. Here, the garden pattern corresponds to the dispersed pattern of urbanization typical for these areas (Verbeek et al., 2011). The garden concentration along the coastline is in sharp contrast with the nearby rural areas. The second urbanization pattern is ribbon development, also reflected in the garden distribution map. The map in Fig. 6 also shows a higher concentration of garden area around built-up road segments.

Overlay with delineations of residential areas show that 67% of the Flemish garden area lies within the residential cores and 33% in non-residential area. The 67% lying in residential cores coincides with 21.3% of the total area of residential cores. The maximum garden share within the residential cores is 45%, the average 23.7%. These figures illustrates the importance of gardens in urban areas, but gardens cover also a non negligible part of the countryside.

Growth of the garden area

Based on the temporal analysis of 44 of the 60 segments, 8.4% of the garden area observed in the period of 2002–2005 was new compared to the period 1988–1990. By extrapolating the percentage of new garden area for the 44 segments to Flanders, it is estimated that 91 km^2 of the 1,100 km^2 garden area in 2005 was new compared to 1988–1990, meaning that about 8% of the domestic garden area in Flanders was created over the analysed time period. The majority of the new garden area is the consequence of new housing development, hence of passive growth (147 gardens accounting for 9.8 ha), while a minority concerns garden expansions (10 expansions or 0.7 ha).

The majority of new garden area within the 60 segments (90%) lies in former arable land. Extrapolated to Flanders this means that 82 km^2 new garden area lies in formerly agricultural land, or a conversion of 1% of agricultural land registered in 1990 to gardens by 2005 (NIS, 2011). According to Kerselaers, Rogge, Dessein, Lauwers, and Van Huylenbroeck (2011) and in the period 2000–2011, 2.3% of farmland was lost to other land uses. Based on our results we can assume that a substantial part was subjected to 'green urbanisation': as urbanisation encroaches upon rural areas (Antrop, 2004; Kerselaers et al., 2011), agricultural land is not only converted to sealed surfaces, but also to the small-scaled open space of domestic gardens.

Table 3
Comparison of garden area coverage with other main land-use categories, in percentage of the Flemish territory.

Sealed surfaces	Forest	Garden	Conservation area	Park
12.9% (Gulinck, Heremans, Dewaelheyns, Meeus, & Bomans, 2007)	10% (Thoen et al., 2002)	8.2%	2.5% (Institute for Nature and Forest Research)	1.6% (VVOG, Fase 1: 1994 Fase2: 1995)

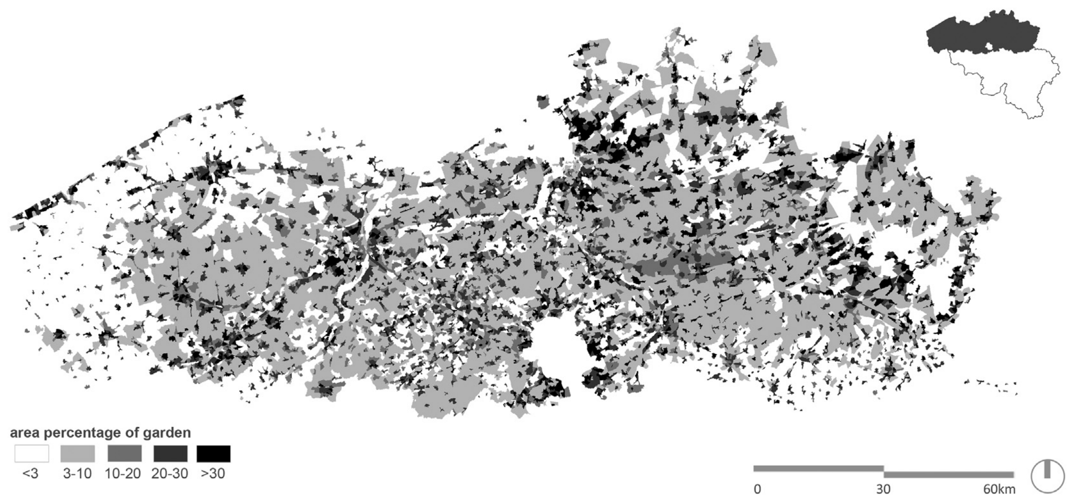

Fig. 5. Percentage of garden area in Flanders per statistical sector, based on the NGI cartographic data (2004)and the orthophotograph analysis.

General discussion

The collection of spatial data on domestic gardens

In this research, the domestic garden area for Flanders has been estimated by combining empirical data with an existing land use map. Our mixed methodology has demonstrated its strength in collecting regional wide data on the spatial footprint of domestic gardens. The empirical data gives information on the exact locations and sizes of individual domestic gardens for the digitized segments. Gill et al., (2008) also collected empirical data by digitizing detailed urban morphology types on aerial photographs. The surplus value of using such empirical data is the higher accuracy at a smaller (time-place) scale. This makes it possible to better grasp land uses and transformations in small-scaled landscapes such as Flanders.

Combining the empirical data with an existing land use map by means of regression makes is possible to extrapolate insights at this small scale to a larger region. We refined the estimation of domestic garden area in the region of Flanders. Remarks are twofold. Firstly, such a regression step does not allow to generate data on the exact locations and sizes of individual gardens for the whole region that is analysed. Secondly, the basic condition for this extrapolation, a reference land use map with a 'garden' category, may not be met in

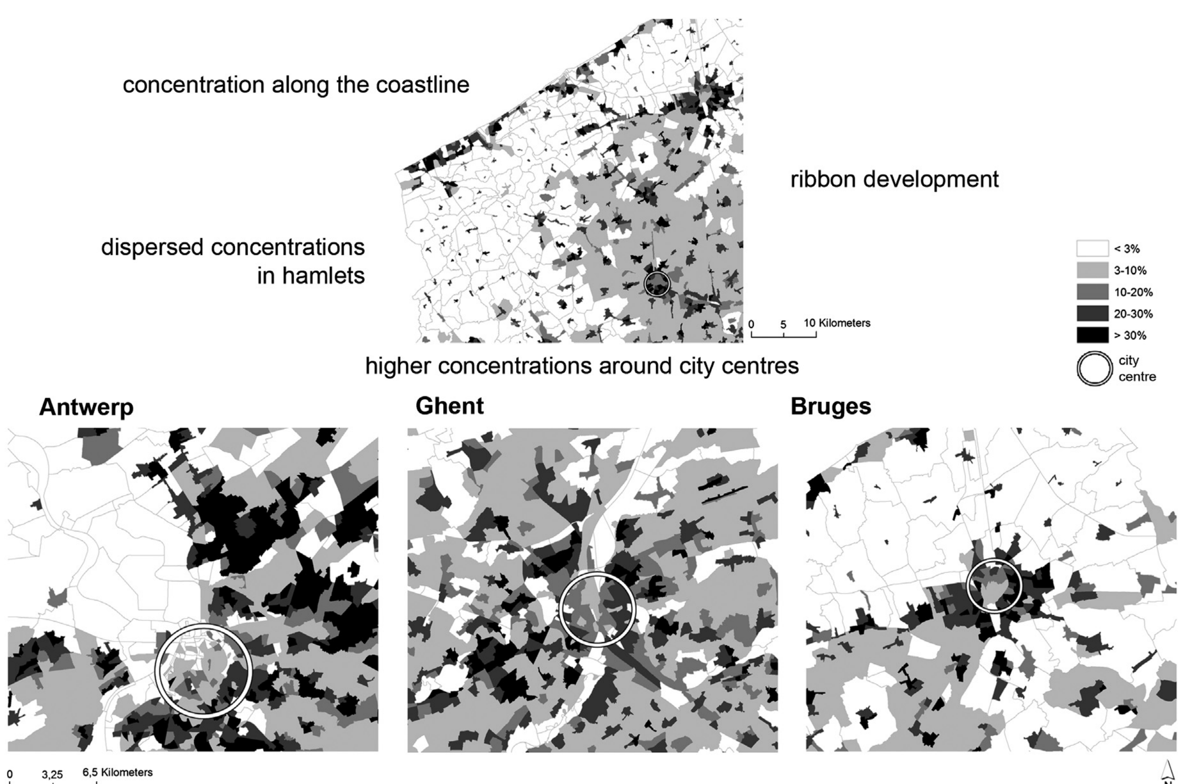

Fig. 6. Summary of the distribution of garden area in Flanders.

other regions or countries. Although not explored in this study, we expect that starting from a more general land use category like urban green would increase the margin of error.

In general, Flanders can be seen as a case study that is inspiring for other regions. Although the methodology was geared on existing data for Flanders, the reasoning behind this methodology is applicable elsewhere. The lack of data on domestic gardens does not only apply for Flanders or Belgium. Also elsewhere it is hard to get a clear idea on the spatial footprint and distribution of domestic gardens (Mathieu et al., 2007) and this for an entire region including peri-urban and rural areas as well as urban areas. Each region or country will need methodological refinements to gear the approach presented in this paper on the datasets that are at their disposal.

A bird's eye-view offers complementary mapping methodologies. Remote sensing techniques are promising in mapping domestic green. Object-oriented classification of high-resolution multi-spectral Ikonos imagery by Mathieu et al. (2007) in New Zealand proved great potential in providing a quick method for obtaining good quality data on domestic gardens in urban areas. So, we see opportunities in the combination of empirical data with high-resolution multi-spectral data for obtaining regional coverage areas of domestic garden area. However, the availability of imagery is a precondition for remote sensing, just as high quality ground truth data for calibration and validation. Moreover, we suggest empiricism to be essential in grasping characteristics of small-scaled and spontaneous land uses and transformations.

Spatial data opens the way to data collection on other garden related aspects. To test whether collected data on other aspects such as the use of fertilizers or pesticides, food production, the presence of trees, amounts of carbon storage within these garden trees, etc. is representative, you need reference data. Getting a grasp of the total area of domestic gardens within a certain region is a first step. Moreover, spatial data allow to position the significance of aspects like the environmental impacts of the (ab-)use of fertilizers, the food production potential or the capacity for storage of carbon in lawn soils or garden trees in domestic gardens towards other land use categories like agriculture (Dewaelheyns et al., 2013).

Just a matter of land use categorization?

The lack of a specific land-use category 'domestic garden' hampers its data collection. In many land use typologies, the category 'domestic garden' blends in other land use categories. Gardens are traditionally considered as an indivisible part of the residential fabric. In Europe for example, the CORINE category 'discontinuous urban fabric' is an 'umbrella' category simply indicating the presence of domestic gardens. Studies working with this category like Tavares, Pato, and Magalhães (2012), should be aware of the domestic garden fraction of this category.

In the case that the land use category 'garden' and derived spatial data exist at the national or regional scale, precautions are necessary. Firstly, the reading of this category should be done with care. Because of its hybrid character (domestic gardens, semi-public and public green etc.) and its physical heterogeneity, the identification of domestic gardens is subject to interpretation, both in the field and on aerial photographs. Domestic green may be hard to distinguish from public green when following identification protocols. Secondly, the garden category easily dissolves in an 'urban' category by up scaling and reclassification processes. Such processes reform existing land use maps to simplified formats, for computational reasons or to provide tailor made data and maps.

Categorization of domestic gardens as an urban land use or planning category leads to a biased image of reality and likely to a bias in land use and open space policies (Maruani & Amit-Cohen, 2007). Like Hasse and Lathrop (2003), we want to nuance the interpretation of urbanization and sprawl phenomena. We demonstrated that 8% of the Flemish area is covered with a land use that is not clearly represented by a land use category. About 21% of the total area of residential cores exists out of domestic gardens. An all-inclusive policy is not possible if land use models or instruments for spatial planning and urbanism are geared on the existing data and acknowledged land use categories. Domestic gardens will not be taken into account. This may lead to underestimation of regionally important services and functions.

Studies modelling urbanization often speak in terms of built-up areas, even those starting from the biodiversity perspective. For example, Rojas, Pino, Basnou, and Vivanco (2013) only take into account the increase of built-up surface, while not considering biodiversity values of the domestic gardens associated to (new) housing. Yet, several studies illustrated the value and potential of domestic gardens for biodiversity (Gaston, Smith, et al., 2005; Goddard et al., 2010; Smith, Thompson, Hodgson, Warren, & Gaston, 2006; Thompson et al., 2003; Tratalos et al., 2007). One can even reverse the logic and consider gardens as subsets of 'open space', since they are not actually fully 'built-up'.

So, current spatial planning policies are locked in clearly defined and standard sectoral land use categories (Larsson, 2006). Census systems collecting statistical land use data are based on existing categorizations of space (Bomans, 2011, pp. 3–10, 35–49, 153–156). Non-orthodox land use categories like domestic gardens easily escape from policy attention since they are not caught by sectoral censuses. Reversely, this lack of policy attention prevents the adjustment of census systems. This phenomenon of circularity in data and information strategies is labelled as the 'categorization bias' by Bomans et al. (2010, 2011). Empirically collected spatial data has the potential to break through this categorization bias.

From individual gardens to the garden complex

The private and small scaled character of domestic gardens (Phillips et al., 2008; Van Delm & Gulinck, 2011) leads to the routinely consideration of gardens as individual objects. Yet, many small units together make up a big area. This is illustrated by our findings that domestic gardens cover 8% of the area in Flanders. This postulation is not only applicable for Flanders but also elsewhere in the world (e.g. Busck, Kristensen, Præstholm, & Primdahl, 2008).

The multiplicity of individual gardens is part of the landscape matrix, and should be considered as such. To be able to pursue sustainable and resilient landscapes that can respond to complex future challenges, it is necessary to consider and manage the landscape as a whole (Fry, 2001; Haines-Young et al., 2003; Saunders & Briggs, 2002; Selman, 2006). Considering the totality of domestic gardens in a certain area as a regional wide landscape structure, a concept which is called the 'garden complex', (Dewaelheyns, Bomans, & Gulinck, 2011; Dewaelheyns et al., 2013) is a complementary up scaling of individual gardens starting from the perspective of open space. Such up scaling can offer both innovative perspectives on our domestic gardens and interesting and valuable insights in fine-scaled, multifunctional and fragmented landscapes.

Gardens in the planning picture

We apparently seem to be faced with a planning paradox. On the one hand, domestic gardens can be considered as a luxury. They occupy a significant area in peri-urban and urban areas, while at the same time there is a growing body of opinion to built less space

consuming. On the other hand, we do believe that the garden complex has strategic value, in relation to the urban fabric as well as in relation with the overall landscape. So, when striving for densification of the built environment, policy should proceed with caution not to lose the ecological and social surplus values of domestic gardens. It is important not to overlook the opportunities of domestic gardens for coping with challenges like climate change and food security. Yet, the presence and increase of domestic garden area should not be seen as an extenuation for ongoing urbanization.

The availability of spatial data is a precondition to start thinking about domestic gardens from a strategic perspective. Adding our work to studies collecting on spatial data of similar encroaching land uses, like the non-agricultural re-use of former agricultural buildings (Verhoeve et al., 2012) and horsification (Bomans et al., 2011a; Zasada, Berges, Hilgendorf, & Piorr, 2013), illustrates the importance of collecting empirical spatial data as a trigger to get them on the agendas of policy and research. Fragmentation and urbanization bring along challenging tasks in Europe (Tavares et al., 2012). Studies like these not only add to the nuancing of land use categorization, but also give better insights in land use dynamics and new perspectives on our landscapes.

Conclusions

The presented research offers another perspective on densification scenarios. The authors argue for a better understanding of the stock of domestic gardens in order to make well-founded choices on urban densification. For this, Flanders can be considered to be an interesting case due to its (historically founded) garden area as well as its small scale and multifunctional character.

The main message of this paper is to acknowledge and start from the spatial reality when developing spatial plans or urban development schemes. We hope that the insights in the spatial footprint of domestic gardens in Flanders as well as the developed methodology presented in this paper will help to launch the debate on the strategic values of domestic gardens.

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